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A Program for the Development of A Benchmark Compartment Fire Model Computer Code

Leonard Y. Cooper, John A. Rockett, Henri E. Mitler and David W. Stroup

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Abstract

With a variety of objectives in mind, many different compartment fire model computer codes have been developed within the fire safety/research community. Yet, no one of these can be described as being a "benchmark" model in the sense that it is reliable enough to be accepted as a standard of reference for the performance of design-oriented fire models. It is the major objective of the Compartment Fire Modeling Research (CFMR) Group in the Fire Safety Technology Division of the Center for Fire Research (CFR) to develop such a Benchmark Compartment Fire Model (BCFM) computer code. This paper describes the characteristics of this BCFM, and outlines the program which will lead to its development.

1. INTRODUCTION

The Compartment Fire Modeling Research (CFMR) Group in the Fire Safety Technology Division of the Center for Fire Research (CFR) was established with the major objective of developing a zone-type Benchmark Compartment Fire Model (BCFM) computer code for simulating compartment fire-generated phenomena. While many different types of compartment fire models are available for fire safety design analyses as well as for fire research, it is the "benchmark" quality of compartment fire simulations that is a focus of activities of the CFMR Group. It is the purpose of this paper to describe the characteristics of the BCFM computer code, and to outline the program of research which will lead to its successful development.

2. AVAILABLE COMPARTMENT FIRE MODELS

There are a number of compartment fire models now in existence. The Harvard and NBS/Harvard family [1-4], COMPBRN [5-7], FAST [8,9], RFIRES [10], DACFIR [11], UNDSAFE [12], and many others. Each has its advantages and disadvantages. Examples of these follow. A comprehensive review of available models is beyond the scope of this paper, and the reader is referred to other articles, e.g., references [13-16], where comparisons between models are presented in substantial detail.

The Harvard-based models (the single room models, Mark 5 and 5.N, and the multiroom models, Mark 6 and 6.N) are the most detailed in terms of the number of dynamic effects taken into account, and they treat most of these phenomena with reasonable accuracy. The models are time-dependent (rather than steady or quasi-steady), and they use fairly robust numerical schemes. They are the closest things now available to benchmark models.

COMPBRN is a quasi-steady model. It takes account of fewer physical processes than do the Harvard-based models, and generally with less accuracy. Thus its capability for accuracy is limited. It uses a prescribed fire with some options including empirical parameters to represent energy feedback, fuel porosity and spread rate. It is very fast.

FAST is a multiroom/multilevel model. It deals only with prescribed fires, it does not take the heating of target items into account, and it does not consider forced ventilation. However, it treats the transport of gases from room to room well, and has excellent associated graphics.

RFIRES is similar in concept and construction to the Harvard-based codes, but over the last several years it has not been kept current with advances in compartment fire modeling. The input data has to be carefully tailored to the particular fire scenarios of interest. Although upper layer temperatures are reasonably well predicted by RFIRES, its ability to simulate target object temperatures accurately requires further development.

DACFIR was developed specifically for aircraft interiors. It calculates the propagation of a fire over a seat in a different way than do the Harvard-based models, and it is potentially better in this regard. It is unique in that it considers smoldering combustion.

UNDSAFE is the only field model to be mentioned here, although numerous others exist. Field models in principle can more faithfully represent physical reality than can zone models. In practice, however, the size and speed of computers typically limit simulations to the order of 10^4 nodes. Thus, for a 3 x 4 x 2.5 m compartment, the primitive cells would be about 15 x 20 x 10 cm on a side, a rather crude representation of the space, for many purposes. Moreover, the calculations for the same simulation time take several orders of magnitude longer than those made with zone models.

3. THE BENCHMARK COMPARTMENT FIRE MODEL DESIGN GUIDES

3.1 General Characteristics and Principal Intended Use of the BCFM

The BCFM and its associated computer code are intended for use as a standard of reference for other zone-type compartment fire models. A second

intended use is to make very reliable predictions. It should be superior to other contemporary models with regard to its ability to accurately simulate the physics and chemistry of compartment fires. It should be numerically robust, i.e., it should converge with high reliability to the solution of its equation set for a broad spectrum of input data, and it should be readily transferable to computer hardware facilities generally available to the fire science and technology community. It need not necessarily execute with high speed, since production calculations are not one of its intended uses. The BCFM code should be well-documented and "user-friendly" in the sense that it is readily usable by skilled practitioners familiar with compartment fire simulations and related data sources. Finally, the computer code should have an internal structure which is flexible in the sense that it facilitates enrichment of the physics and chemistry included, and the numerics used. This flexibility will allow the code to be usable as a vehicle for testing new physical/chemical process algorithms. Also, such flexibility will permit relatively frequent official and published updates of the BCFM, allowing it to be readily maintained at a technical level which is current in relation to advances in fire science.

The above paragraph describes important characteristics of the BCFM computer code in a general and open-ended manner. In principle, no explicit bounds of accuracy, completeness, etc. should be placed on any aspect of the BCFM to be developed. Yet, to develop the model and its computer code, limitations in scope must inevitably come into play. For example, limitations in scope are required to make BCFM development objectives compatible with CFMR program resources. Toward these ends, some bounds will be required on the physical complexity of the compartment spaces which the BCFM will handle, and

on the number of and accuracy with which individual processes will be treated. Other items whose scope requires clarification are the type of numerics used for solving the governing BCFM equations, guidelines on the design of the user interface, and those items which are relevant to the design or structure of the computer code itself. All of these bounds and limitations will be discussed below.

The BCFM development program will be carried out with the clear recognition that developing a benchmark model and computer code must be viewed as a continuing, long-term process. Nevertheless, the tasks described here will be directed toward the development of a definite product, referred to throughout this paper as the BCFM. Within the context of past and anticipated future progress in fire science, it is recognized that a more appropriate designation might be the next generation BCFM.

3.2 Complexity of the Enclosure

Consider a fire in a room (compartment) or grouping of rooms of a building or other enclosure. The physical enclosure of interest here would include those portions of the building which influence the characteristics of the enclosure environment (i.e., environments with conditions significantly different from the ambient) as it develops during the course of the fire. Frequently the outside environment will influence the fire conditions, and in such instances it must be involved in an analysis of compartment fires.

The enclosure of interest would include all compartments which communicate with one another in such a manner as to affect the flow of venti-

lating air to and/or combustion products from the compartments actually involved in the fire. In this sense most spaces of a building could be a part of the enclosure. However, for many purposes this broad interpretation of the extent of the enclosure is unnecessary. For example, while there is a strong coupling between fire growth and the fire-generated environment in rooms of fire involvement, and, possibly, in "freely connected" adjacent spaces, the coupling in real fires between fire growth and conditions in "distant" spaces is typically rather weak [17,18]. On the other hand, fire-generated phenomena in rooms of fire involvement and in adjacent, connected spaces influence strongly properties and rates of generation of hot and toxic products of combustion which are key to the development of hazardous conditions in such "distant" spaces.

The focus of the BCFM is on a capability for providing benchmark simulations of fire growth phenomena and of the fire-generated environment in rooms of fire involvement. In view of the above discussion, it is also important that the BCFM be capable of simulating conditions which develop in rooms "nearby" to the rooms of fire involvement. Finally, consistent with its focus there is no strong requirement for the BCFM to treat "distant" spaces. By excluding "distant" spaces, thereby limiting compartment complexity, a significant simplification in BCFM scope is achieved. Relative to the question of compartment complexity, all of the latter guidelines have been adopted for the BCFM.

3.3 Modeling Detail of the Physical Phenomena: The Code's Module of Physics Subroutines

3.3.1 Compartment Fire Models and Compartment Fire Model Computer Codes

Many different and often strongly coupled physical and chemical processes occur during a compartment fire. A compartment fire model is a set of equations or algorithms which describe these individual processes. The couplings between the different physical and/or chemical processes must be reflected by similar coupling between their mathematical descriptions. Certain features of compartment fire phenomena lend themselves to relatively simple mathematical descriptions. Yet, except for the very simplest of compartment fire models, computer-aided calculations are required to solve the model equations, i.e., to obtain a mathematical simulation of the compartment fire phenomena of interest. Such calculations require a compartment fire model computer code which is designed to solve the equations describing the physical/chemical processes. The equations are represented by subroutine software which make up a key module of the code.

3.3.2 Two Kinds of Modeling Detail

There are two kinds of detail which characterize the modeling capability of any particular compartment fire model. These define the essence of an overall fire model, and are useful in distinguishing one model from another.

The first kind of detail involves the number and types of processes taken account of. The second kind of modeling detail is related to the ability of algorithms to produce accurate simulations. Such reliability would be established, for example, through experimental validation.

It is possible to develop a model with a major focus on the detail achieved through the inclusion of as large a number of processes as possible, even though this will require that some of the algorithms, although physically based, are not-well proven. To justify this approach, one can argue that the resulting model would lead to simulations, which, although potentially inaccurate, achieve an overall acceptability by accounting for the effect of many interacting processes in a rational way. Alternatively, it is possible to develop a model involving detail obtained from exclusive use of highly accurate algorithms (which would presumably model the dominant processes in fire scenarios of special interest). Such a model would ignore many obvious, but presumably secondary, processes. To justify the latter kind of model one can reasonably argue that a strong sense of accuracy, albeit for only limited conditions, is fundamental if the results of compartment fire model simulations are to be taken seriously.

It is evident that a balance must be struck when addressing the question of which kind of modeling detail to stress in the BCFM. As will be discussed below, the BCFM will be designed with some flexibility in this regard. Nevertheless, in terms of a general guideline, accuracy in algorithm simulation is the focus most consistent with the idea of a benchmark model. It is this focus which will be adopted for the BCFM, and which will be a major feature distinguishing the BCFM from other available compartment fire models.

3.3.3 The Appropriate Level of Modeling Detail for the BCFM

The notion of mathematically describing processes with "appropriate detail" is now introduced. The task at hand is to identify guidelines which

would lead to a level of detail which is both appropriate for the BCFM, and consistent with available resources. This must be done with an eye on code flexibility, and with the focus on modeling accuracy in mind.

Fire science and technology dealing with compartment fire processes is relatively young. It is reasonable to anticipate many decades of significant advances in the ability to understand and simulate these processes. At the present time compartment fire processes can be placed into three different classes:

1. Processes already understood to the extent that at least minimally accurate algorithms exist and have been tested.

2. Processes like those in class 1, but for which no suitable algorithms exist; and processes which, while not well understood, have been identified as being important, and which are already under serious investigation in the fire research community.

3. Processes which have been identified as being important, but for which no adequate investigations have yet been made (e.g., the principal variables on which the process depends have not yet been identified).

Note that current and future research will eventually change the category of any given process now in classes 2 or 3. Also, while the class 1 processes are already reasonably well understood, it is likely that even for these, future theoretical and experimental studies will lead to a capability for even higher accuracy in their current simulation [19].

To include class 3 processes in a new model would generally require that it include certain "open-ended" features. Such features, set in place for the purpose of contingency planning, might lead to excessive developmental resource requirements. For this reason, only processes in classes 1 and 2 will, by design, be included in the BCFM. Thus, no special allowances will be made in the BCFM to anticipate the direction of future research on compartment fire processes. Note that this limitation in scope does not preclude the possibility of eventually including some current class 3 processes in the BCFM as they become better understood.

Class 1 processes will be included in the BCFM. Algorithms successfully used in the Harvard-based computer codes [1-4] will be taken as a guide for the accepted extent of this class, although algorithms from other sources will be included as well. The catalog of Harvard-based algorithms will also be used as a guide for the acceptable degree of modeling accuracy. In view of the BCFM focus on "benchmark quality", however, some of these algorithms will require significant improvements, and, possibly, the introduction of additional variables. Some examples of NBS/Harvard algorithms requiring improvements include those which describe:

- plume dynamics
- burning in the upper layer
- forced ventilation
- convective heat transfer to ceilings
- mixing between upper and lower layers due to the inward and outward components of vent flows
- combustion product generation rates

The flexibility of the structure of the computer code will be developed so that, to the extent practicable, improvements to these algorithms will be easy to incorporate into the BCFM. However, the improvements which can thus be made will be limited. Eventually the need will arise for a new generation of BCFM, which will be able to transcend these limitations, and incorporate a wider class of improvements.

The following is a partial list of class 2 compartment fire-related processes which will eventually be included in the BCFM:

- fire growth and spread on vertical surfaces
- radiation absorption of near-surface pyrolysis products
- mixing between layers and convective heat transfer to walls due to wall flows
- heat transfer to floors and floor heating
- sprinkler link response
- detector response

The above two lists are only partial, and other processes may be included. Over the course of BCFM development, additional processes that are not now obvious are also likely to be added to the second list. However, the addition of entries to either of the lists cannot be open-ended, since each such addition must be matched with corresponding extensions in the BCFM development time interval. The situation will, of necessity, lead to known gaps in BCFM capabilities. For example, while better algorithms for the processes of fire growth and flame spread on horizontal surfaces are future necessities, such algorithms do not appear to be at hand. It is for this

reason that they are not identified above for improvement and inclusion into the BCFM.

3.3.4 Coding Standards for the Module of Algorithm Subroutines

All physical processes included in the BCFM will be represented as entries in a catalog of subroutine software. In the development of the Harvard 6 multi-room fire model [2], considerable effort was expended in establishing and implementing coding standards for these subroutines. These standards are consistent with state-of-the-art computer software practices, and should be directly applicable to the BCFM computer code.

3.4 The Numerics Software Module

The solutions for the coupled equation sets of the physical/chemical compartment fire processes will be carried out by the numerics software of the BCFM computer code. When making such software choices for the new code, the experience with the numerics software of the Harvard-based codes [1-4,22] will be taken into consideration.

The numerics of the NBS/Harvard 6 codes are derived from an algebraic- and differential-equation solver developed by C.W. Gear [3,20]. Certain aspects of these numerics might still be considered state-of-the-art. However, it is likely that improvements are now achievable. For example, as suggested by D. O'Leary [21], while the variable elimination procedure developed for the Harvard 6 numerics [2,22] may reduce the number of unknowns, the implicit assumption that the smaller variable set can be more readily solved

may not always be true; indeed, it may have the disadvantage of making the resulting system of equations more difficult to solve. However, there are techniques which can modify Gear's routines to take advantage of the sparse Jacobian matrix generated in the calculation. The Juggle routine used in Harvard 6 [2,22] is one such technique. Others might lead to an improved approach for solving the BCFM system of equations. The objective would be to make the code more reliable than it would otherwise be, possibly faster, and easier to understand and modify.

In general, it is necessary that a review of the state-of-the-art of relevant numerics software be carried out as a preliminary step in the development and adoption of an optimal design for the BCFM numerics module.

3.5 The User Interface Module and User Manual Documentation

A well-designed user interface module and supporting user manual documentation will be key to the user-friendliness of the BCFM computer code. If these are developed to a high quality, much will have been done to insure the code's broadest possible utility within the community of its intended use. In recent years there have been significant advances in user interface software practices, not taken fully advantage of in available compartment fire model computer codes. Some of these new procedures would be directly relevant to the BCFM computer code.

A variety of material property, fire growth, and other data will be required as input to the BCFM [23]. A user-interface module capable of accessing an independently maintained base of such data would be a particular-

ly attractive feature of the BCFM. Having this would minimize and often eliminate the need for the user to refer to outside sources for this data which is typically scattered about in the literature, and not readily available.

As will be discussed below, the flexibility of the BCFM will be strongly influenced by the software design in general, and the design of the user-interface module in particular.

3.6 The Structure of the Computer Code

The BCFM will include an overall code structure which will link together the three major software modules: the user-interface module, the numerics software module for solving the coupled equations, and the module of physics subroutines which are the coded versions of these equations.

As with the other aspects of the BCFM code, the Harvard and NBS/Harvard code development experiences of the last several years will be used as a basis on which to build an improved framework for overall code structure. To provide further guidance in this regard, a general review of other relevant computer codes will be carried out. This will lead to useful ideas on BCFM code structure optimization.

3.7 Guidelines for BCFM Flexibility

The design of the overall code structure and of the modules will be influenced by guidelines for code flexibility. Flexibility in at least four different areas is desirable.

First is the capability to easily enrich the BCFM with new or revised physics or numerics algorithms. Such flexibility will allow the code to be conveniently used as a vehicle for testing such algorithms. It will also allow revisions of the code to be conveniently prepared and published.

Second is the ability to select one from among a number of alternative subroutines which describe a particular process. For example, the alternative subroutines could be distinguished from one another by their degree of proven reliability in a particular type of application. The selected subroutine would then be used with the other subroutines which, together, would make up an overall set of model equations for simulating a particular fire scenario being studied. An example of this type of flexibility, already included in the NBS/Harvard 5.2, is the ability to choose one from among several plume dynamics subroutines [24].

The above-mentioned review of current numerics software literature will likely reveal attractive and relevant options for BCFM numerics software. A final type of flexibility involves the ability to test and/or implement such alternative numerics software options in the numerics module of the code.

4. EXAMPLES OF THE ANTICIPATED USE OF THE BCFM

Three major uses of the BCFM can be anticipated: (1) calibration of other zone-type models, an intended use; (2) calibration of the BCFM itself against experimental fire data, an essential part of the BCFM development and, therefore, an intended use; and (3) use of the BCFM as a (production) engineering analysis tool, an inevitable result of the existence of the BCFM,

but a use distinct from the above two intended uses. In the present litigious climate which surrounds issues of fire safety, these three uses inevitably become tightly coupled.

The major use of the BCFM will be as a standard of reference against which other models, with presumably fewer physical phenomena details, can be evaluated. For example, in the evaluation of models designed to be economically executed in conjunction with CAD systems.

In many cases (e.g., for legal reasons) users of compartment fire models may feel constrained to use only the "most complete" model available, and will accept possible operational inconveniences of the BCFM in order to achieve this.

Although no calibrations of one model against another more complete model have been reported, there are several studies where simulations from different fire models have been compared (e.g., [13-16] and [25]). While [25] does not explicitly present comparative predictions of the models it considered, it does discuss their physics; no conclusions are drawn, except by inference, about the limits of model applicability.

Presumably the BCFM calibration of a candidate model would involve four steps:

1. Defining the area of and limitations on the intended use of the candidate model.

2. Defining the common use area, if any, between the candidate and the BCFM.

3. Comparison of the models within their common use area(s). This could involve analysis of the model structures, as in [25], as well as comparative numerical results for a series of simulations.

4. Drawing conclusions from the results about the probable accuracy and validity of the candidate model within its own intended use area.

Calibrations of fire models against experimental data already exist (e.g., [1,25-28]). In these studies, data from a series of related experiments are compared with simulations. Conclusions are drawn about the accuracy, validity and limitations of the simulations. These conclusions extend to observations about physical effects not modeled or incompletely treated whose inclusion or improvement would affect these particular simulations and the future, general use of the fire model. Published studies of this type have been carried out by persons associated with the model development, and are based on experimental data developed within their own organizations. While the successful development of the BCFM will require comparisons between calculations and experimental data, in order to minimize bias it is not necessary, and may not be desirable, for final calibrations of the BCFM to be carried out by its developers.

Fire models can also be used as tools of engineering analysis (e.g., [29-33]). They may be used as an adjunct to correlation and analysis of experimental data [29,30]; to extrapolate from available data to situations

not tested [31]; or to predict fire performance of a building [30,32,33] so that recommendations about facilities can be made during the building design. While the BCFM might be used in this way, it is not one of its intended uses in the sense of its being optimized for this purpose.

5. ACTIVITIES REQUIRED FOR MODEL DEVELOPMENT

In the above discussion, guidelines were presented for the development and ultimate scope of the BCFM computer code. Development of the code will require activities in four different areas:

1. the overall code structure;

2. the physical process algorithms and corresponding module of subroutines, which will be published in the form of a readily available and transportable catalog;

3. the numerics software module; and

4. the user interface module and user manual.

All of the above activities are planned for completion in approximately three years.

A significant portion of the work associated with the code development and documentation, all activities except those of item 2, will involve a mix of high level numerical analysis, computer science and structured programming.

Complementing this software development activity will be the previously described task of developing and improving the required physical process algorithms and subroutines. This activity is fundamental to compartment fire modeling research in that its products will be useful for model building activities throughout the entire fire science community.

The development and improvement of physical process algorithm requires significant manpower resources. It has been, and will continue to be carried out by the CFMR Group, by other groups within CFR, and at institutions other than NBS. The CFMR Group effort in this area is now entirely focused on items delineated above in Section 3.3.3, The Appropriate Level of Modeling Detail for the BCFM. The research outlined there will be completed in a time-frame consistent with the approximately three years of the above-mentioned software development. Advancements in algorithms and subroutines completed after this time will be used to enrich, revise, or produce new generations of the BCFM.

Overall documentation for the BCFM will include a reference catalog of all physical process algorithms and corresponding subroutines used. The catalog itself will be transportable and usable in other compartment fire model computer codes, and on commonly available computer hardware. Preliminary development work on the algorithm/subroutine catalog has been initiated, and a preliminary version of the catalog with recommendations on the final product's style and format will soon appear [34].

6. SHORT-TERM AND LONG-TERM OBJECTIVES

6.1 A Two-Stage Effort in Software Development

From initiation of BCFM software development work a three year effort will be required before a final product is available. There is an immediate and continuing need for a compartment fire model computer code with benchmark-quality features. It is this need which has motivated a two-stage effort in the BCFM development program.

6.2 The First Stage Effort - Testing Ideas on a Prototype One-Room Compartment Fire Model

The Harvard and NBS/Harvard codes were developed at Harvard University through funding from the NBS/CFR Extramural Research Grant Program, and more recently, at NBS/CFR where the development program was consolidated in 1983.

Since 1981, significant progress has been made as a result of the Harvard University and NBS/CFR research efforts. This progress is manifested in the various research/development versions of the codes. The most recent versions of these codes, the single-room, "5.N" codes and the multi-room, "6.N" codes, are the closest to benchmark quality of all compartment fire models now available. Except for one, these versions must all be considered to be developmental or research codes. The exception is the "official" Harvard 5 code, which was completed and "fixed" in 1981 together with supporting documentation [1]. Unfortunately, while this latter reference document provides a technical description of the Harvard 5 code, it is not a user's manual, and no such user's manual is available.

There is a need to consolidate the advances which have been incorporated into the NBS/Harvard 5.N codes; to publish an official, well-documented, high quality, one-room NBS code; and to do this in a timely manner.

In response to the above need, a CFMR Group project has been established to generate and publish such an official NBS code by the end of FY 1986. The code will involve a consolidation of the capabilities of the Harvard-based one-room codes. It will be supported by a user's manual and other appropriate documentation. This project is considered to be a first-stage effort in the development of the BCFM, in that it will involve the testing of BCFM ideas on a prototype, one-room compartment fire model.

6.3 The Second Stage Effort - The BCFM

The major and second-stage BCFM software development effort described in the bulk of this paper will be initiated during FY 1986. A development period of approximately three years will lead to the first generation BCFM. It is anticipated that the initial phases of this work will be carried out simultaneously with the latter part of the stage-one project, and that the time interval of concurrent development will lead to mutual enhancements to the two efforts.

7. SUMMARY

The Compartment Fire Modeling Research Group has been formed at the Center for Fire Research of the National Bureau of Standards to develop a zone-type Benchmark Compartment Fire Model (BCFM) computer code for simulating

compartment fire-generated phenomena. The purpose of this paper was to describe the characteristics of this BCFM, and to outline the elements of a program for its development.

Guidelines for the scope of this effort were presented in some detail. These will provide guidance in the key areas of BCFM code development, which include: bounds on the physical complexity of compartment spaces which the BCFM will be capable of handling; limitations in the detail with which individual compartment fire-driven processes will be treated in the overall model; the type of numerics to be used for solving the governing BCFM equations; the design of the computer code's user interface; the design of the basic structure of the code; and the range of the code's flexibility within its intended use as a standard of reference for other zone-type compartment fire model codes, and as a vehicle for testing newly developed or improved physical/chemical process algorithms.

Compatible with its established scope, specific activities required to carry out BCFM code development have been outlined. These activities include (1) the development of required new and improved physical/chemical process algorithms, and their corresponding subroutines which will lead to a transportable catalog of these algorithms and subroutines; and (2) the development of overall software and its documentation. The latter activity will include the software development associated with the code's numerics module, with the user-interface module, and with the overall code structure.

The computer code under discussion will be unavailable for approximately four years. For this reason, it cannot satisfy the immediate and continuous

need for a well-documented, state-of-the-art, compartment fire model computer code with benchmark-quality features. In response to this need, a project to generate and publish such an official NBS one-room code in approximately one year has been initiated recently. The code will mainly be the result of a consolidation of many of the recent advances embodied in the NBS/Harvard 5.N and 6.N research/development codes. This project is considered to be a first-stage effort in the development of the BCFM, in that it will involve the testing of BCFM ideas on a prototype, one-room compartment fire model.

The development of the BCFM computer code which is the subject of this paper can be thought of as the next major step within the progressive development of benchmark compartment fire model computer codes. Although outside the scope of present planning, it is clear from Emmon's prophecy of reference [19] that future advances in fire science and technology will eventually render even this BCFM obsolete, thereby leading to the requirement for yet another generation BCFM.

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A Program for the Development of a Benchmark Compartment Fire Model Computer Code

5. AUTHOR(S)

Leonard Y. Cooper, John A. Rockett, Henri E. Mitler and David W. Stroup

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

With a variety of objectives in mind, many different compartment fire model computer codes have been developed within the fire safety/research community. Yet, no one of these can be described as being a "benchmark" model in the sense that it is reliable enough to be accepted as a standard of reference for the performance of design-oriented fire models. It is the major objective of the Compartment Fire Modeling Research (CFMR) Group in the Fire Safety Technology Division of the Center for Fire Research (CFR) to develop such a Benchmark Compartment Fire Model (BCFM) computer code. This paper describes the characteristics of this BCFM, and outlines the program which will lead to its development.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

compartment fires; computer programs; fire models; fire research; room fires

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